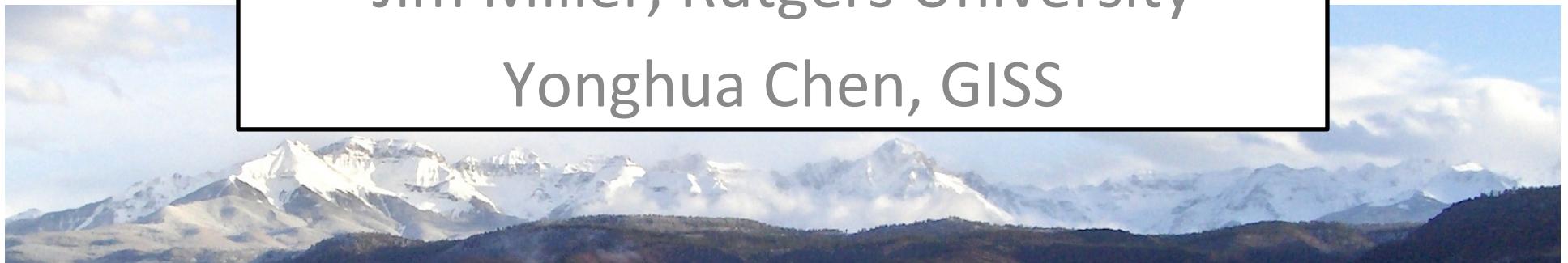


# Climate change in high elevation regions: a short overview and some preliminary data analysis

Catherine Naud

Jim Miller, Rutgers University

Yonghua Chen, GISS

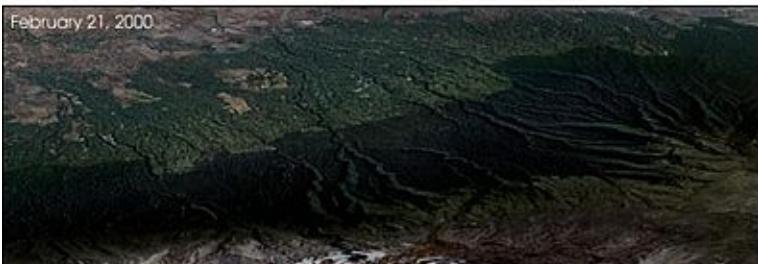


# Layout

- Temperature trends at high elevations
- Other trends
- Cloud sensitivity?
- Snow-ice albedo?
- Water vapor?
- Model studies
- The satellite view: strengths and weaknesses



# Quick facts



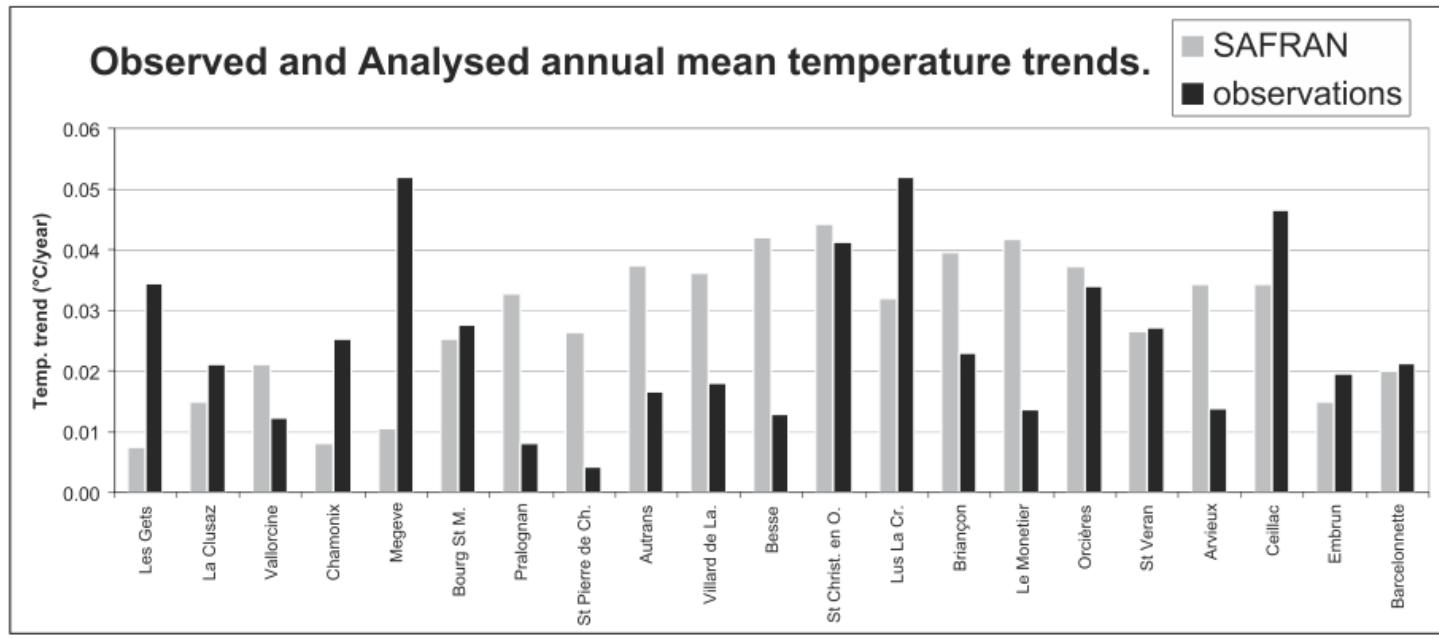
- Tropics: Kilimanjaro in Africa has little ice left
- Midlatitudes: ice melt affects water supply of large populations:  
Tibetan Plateau (3<sup>rd</sup> pole): China, India  
Rockies: western US  
Andes: western south America  
Alps: central Europe



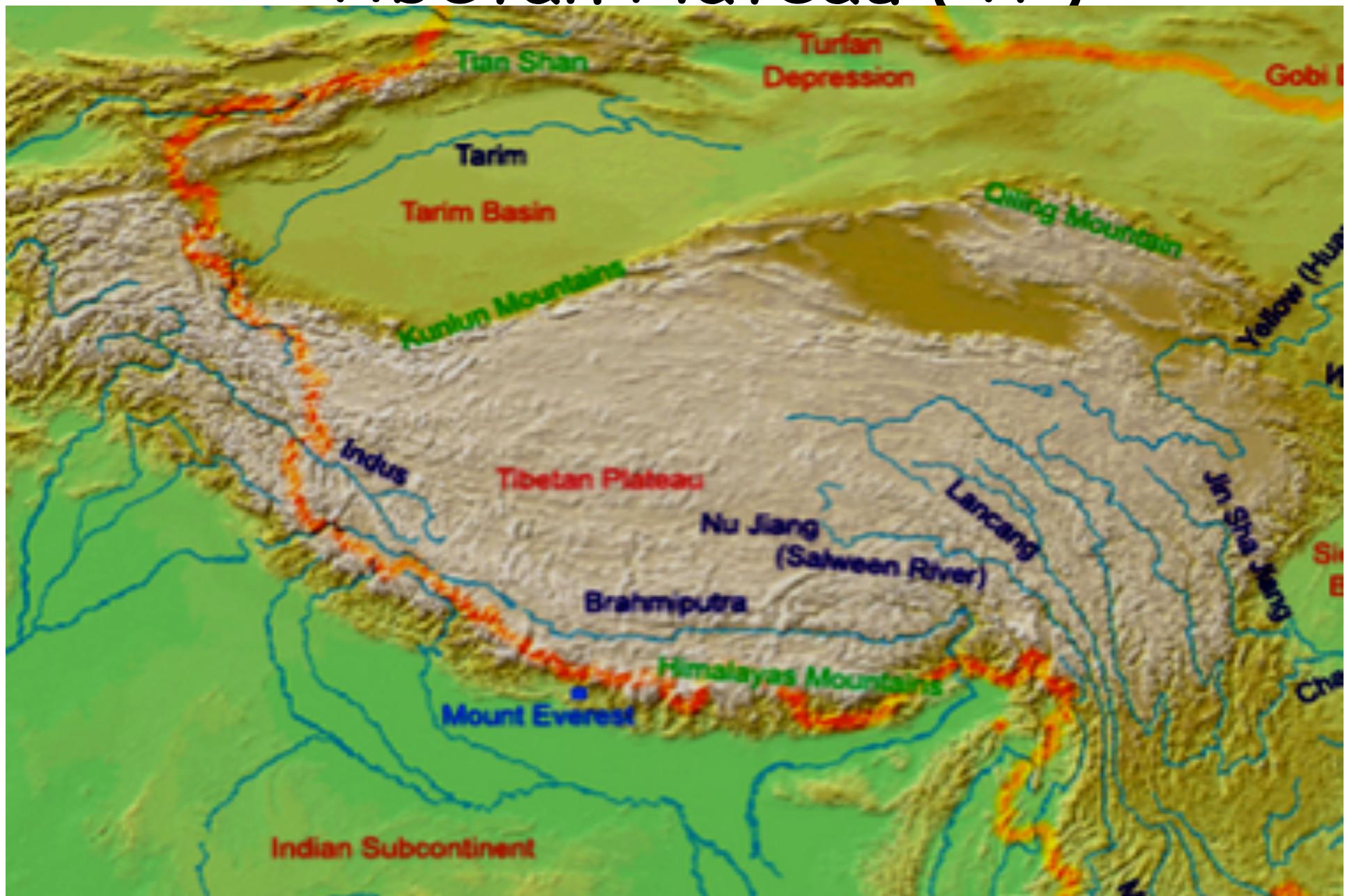
# Temperature trend: Alps

- Warming trend: 1°C for 1958-2002 or 0.23°C/decade

*Durand et al. JAMC 2009*



# Tibetan Plateau (TP)



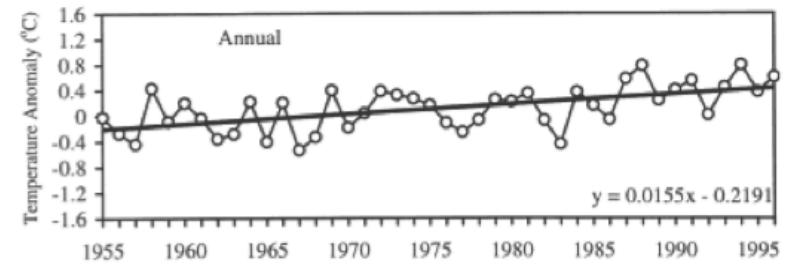
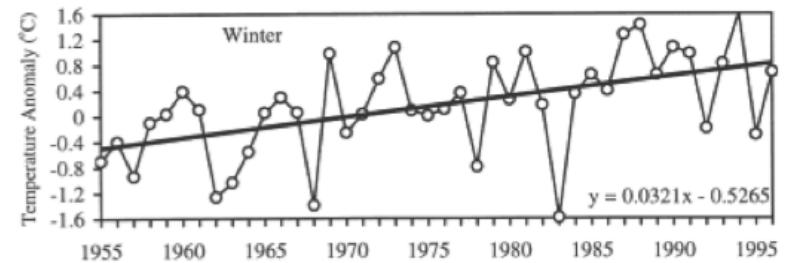
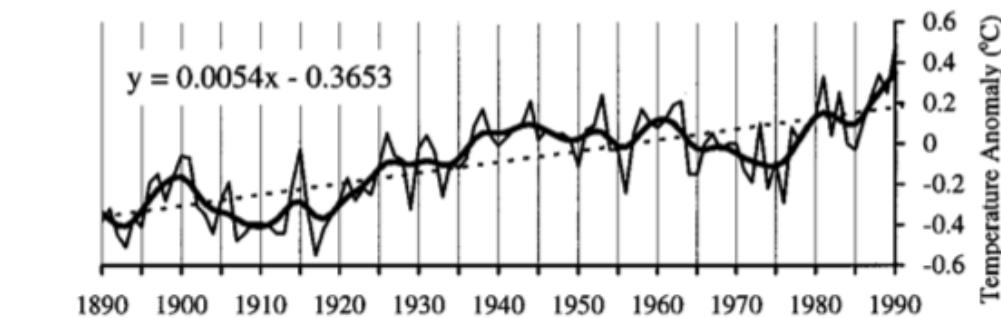
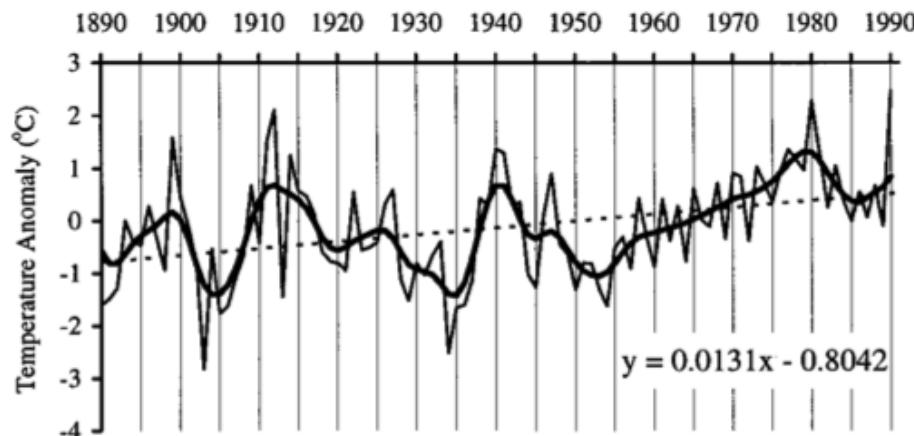
# Temperature trend: Tibetan Plateau

Trend over the Plateau (1 station,  $+0.13^\circ \text{C}/\text{decade}$ )

v.s.

Trend for NH ( $0.05^\circ \text{C}/\text{decade}$ )

*Liu and Chen, IJC 2000*



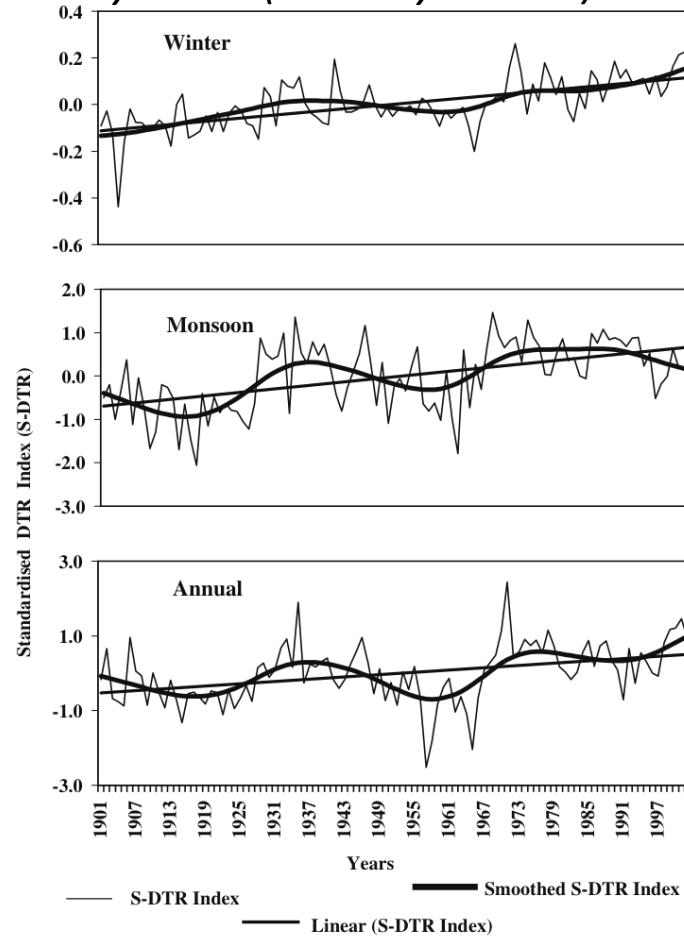
Winter trend ( $+0.32^\circ \text{C}/\text{decade}$ ) vs  
annual trend ( $+0.16^\circ \text{C}/\text{decade}$ )  
(97 stations)



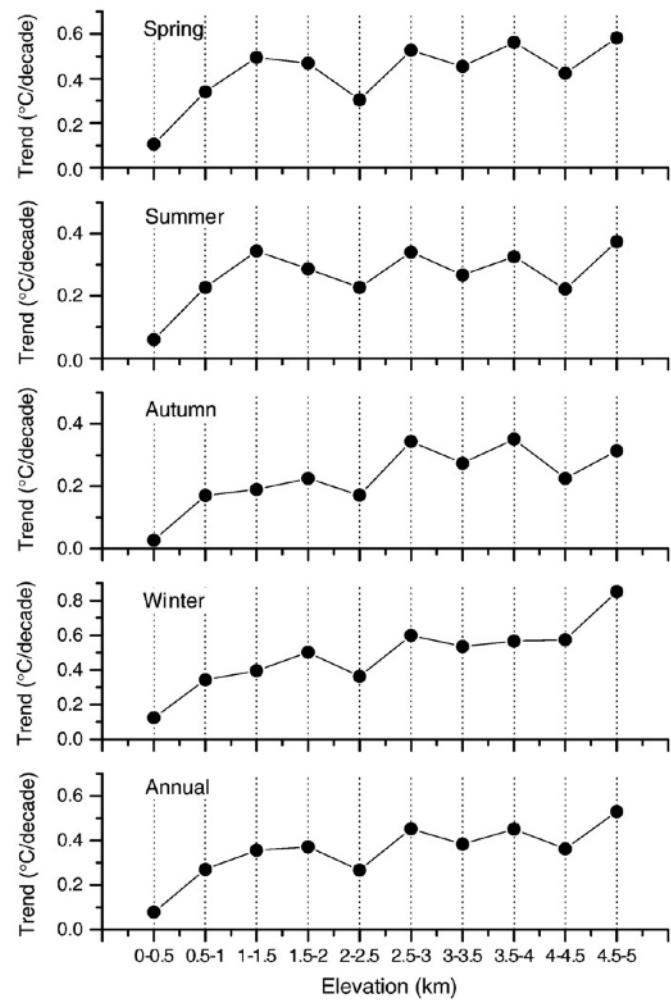
# Temperature trend: Tibetan Plateau

Increase in diurnal temperature trend  
(max T increase faster than min T)

*Bhutinayi et al. (Clim. Dyn. 2007)*



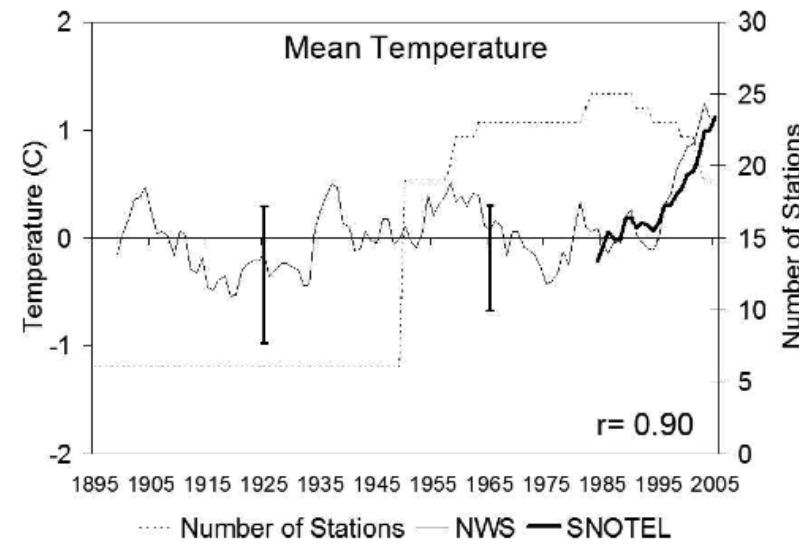
Trend vs elevation: increase with Z  
*Liu et al. (Glob. Planet. Change, 2009)*



# Temperature trend: Rockies

- Increase in temperature in southwestern Colorado:  $1^{\circ}$  for 1895-2005, or  $0.09^{\circ}\text{C}/\text{decade}$
- Max T increase most in summer and min T in winter

*Rangwala and Miller (AAARes 2010)*



# Temperature trend: Rockies

Koppen Tundra 1901–1930



Koppen Tundra 1987–2006

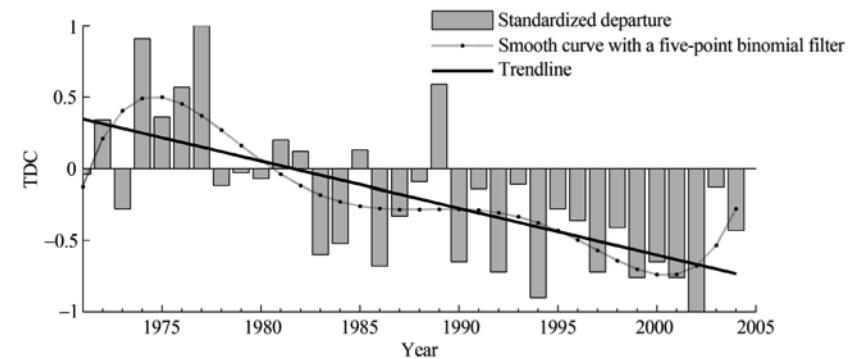


- Alpine tundra climate type receding in western US (region where maximum temperature during warm season between 0 and 10°C)  
*Diaz and Eischeid (GRL 2007) (left)*



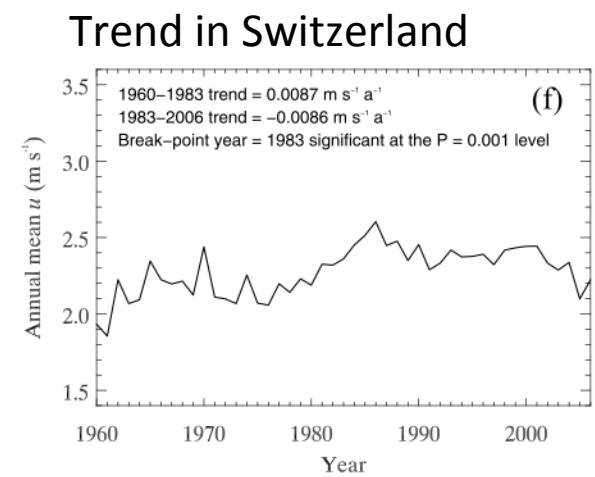
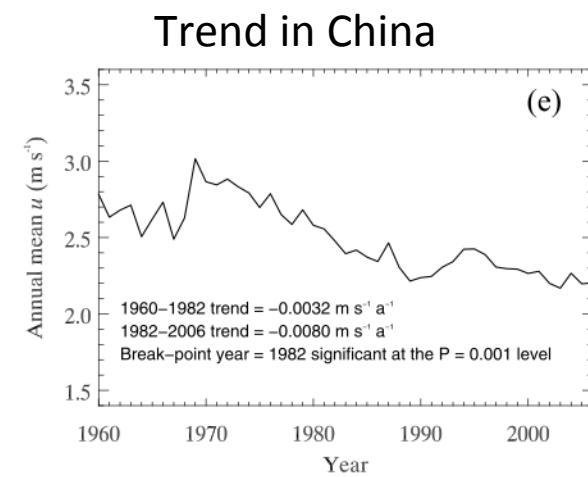
# Other trends

Clouds: decrease in cloud amount  
over Tibetan Plateau 1971-2002  
*Zhang et al J. Geogr. Sci. 2008*



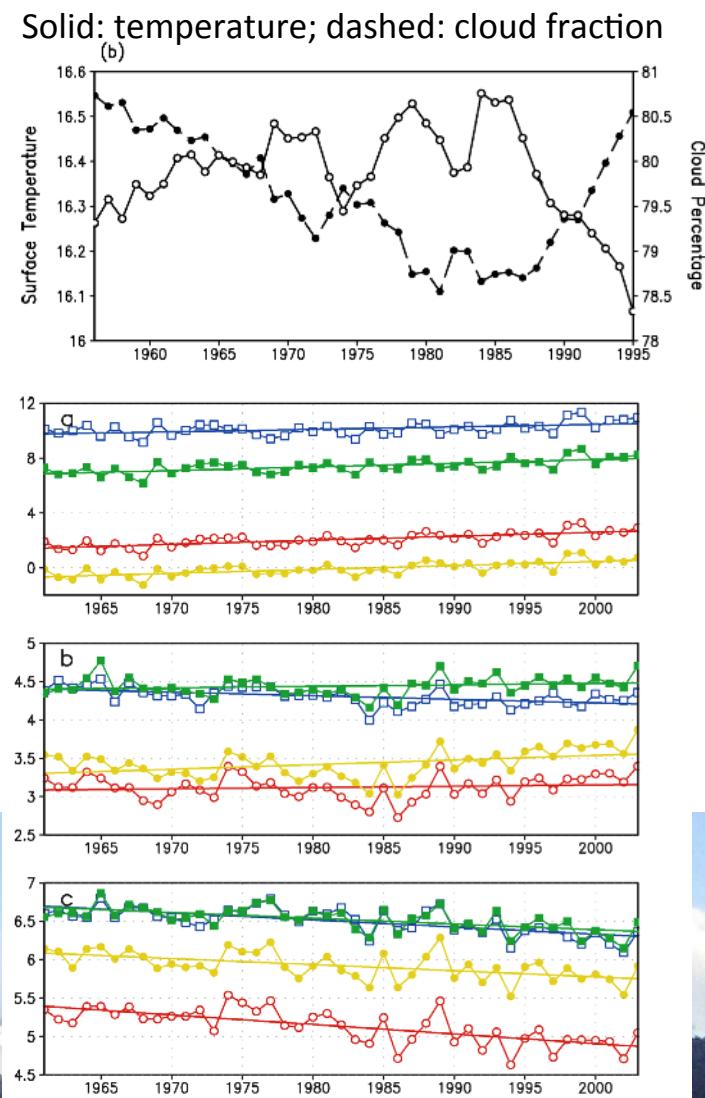
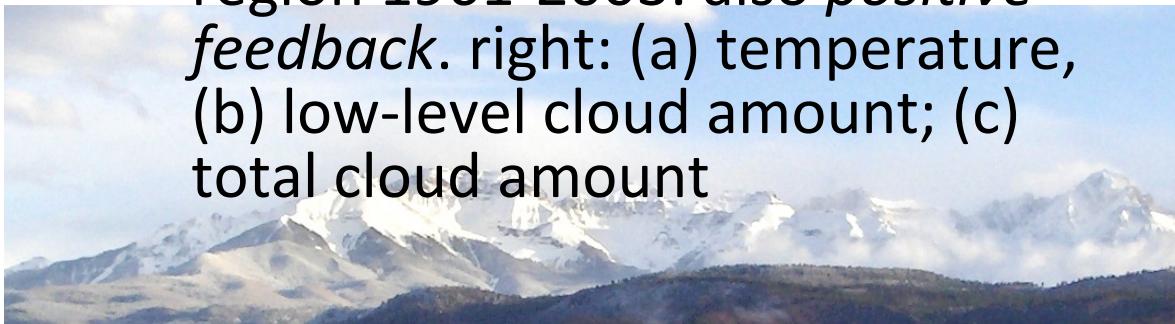
Near-surface winds:  
decrease in speed  
1960-2006 in China and  
Alps. Greater rates with  
altitude.

*McVicar et al. GRL 2010*



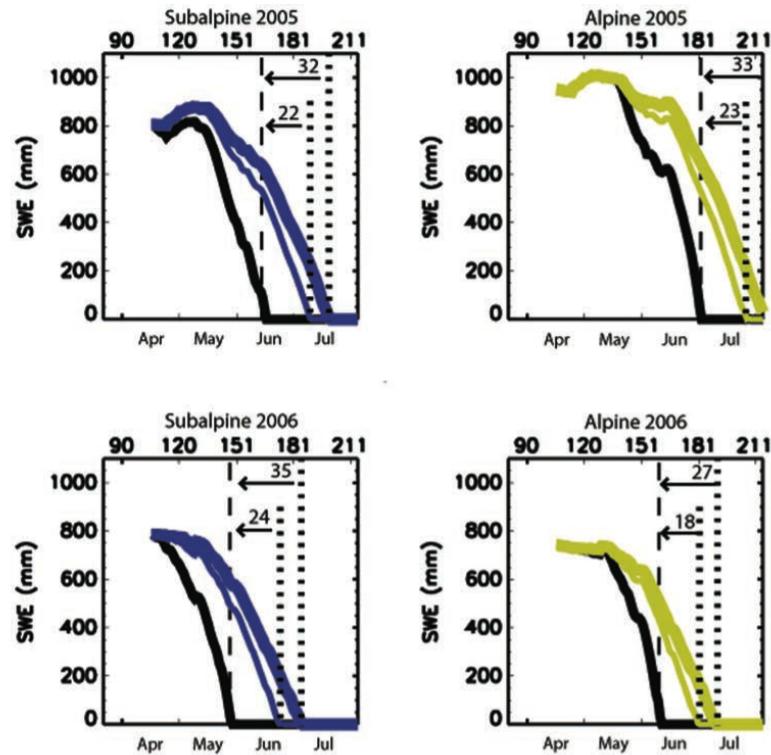
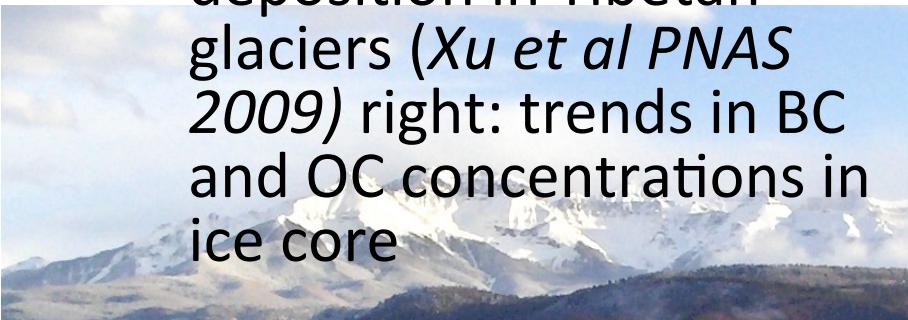
# Sensitivities: clouds?

- Optically thick stratus deck over Tibetan plateau found to change with temperature: *positive feedback* => but eastern plateau shows cooling trend (Yu et al., JCLI 2004)
- Total cloud amount increase with temperature at night but decrease with temperature during the day (Duan and Wu GRL 2006)=> warming trend found over larger region 1961-2003. also *positive feedback*. right: (a) temperature, (b) low-level cloud amount; (c) total cloud amount

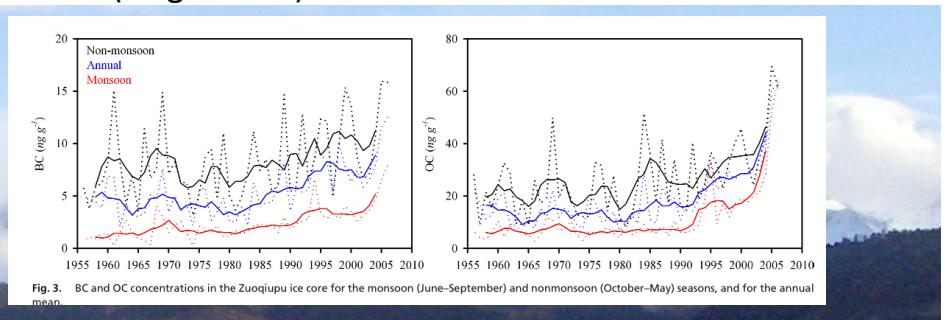


# Sensitivities: Snow-ice albedo?

- Dust: desert soil disturbance=> dust deposition in Rockies=> darker snow=> earlier melt + more shortwave absorption (*Painter et al. GRL 2007*)  
Increase in dust deposition in Mount Everest ice core since 1800s
- Soot: increase in soot deposition in Tibetan glaciers (*Xu et al PNAS 2009*) right: trends in BC and OC concentrations in ice core



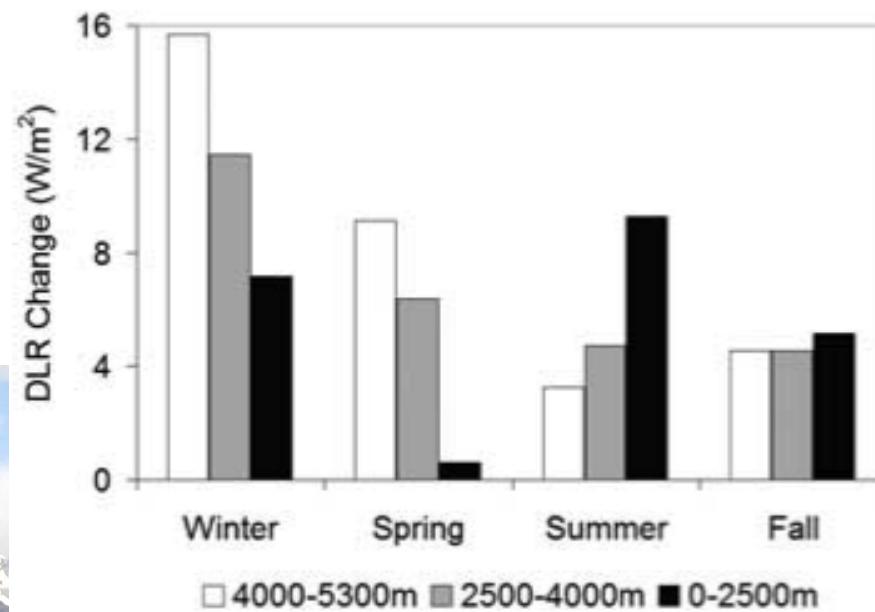
Snow water-equivalent change in 2005 (“normal” dust) vs 2006 (“high” dust)



# Sensitivities: water vapor

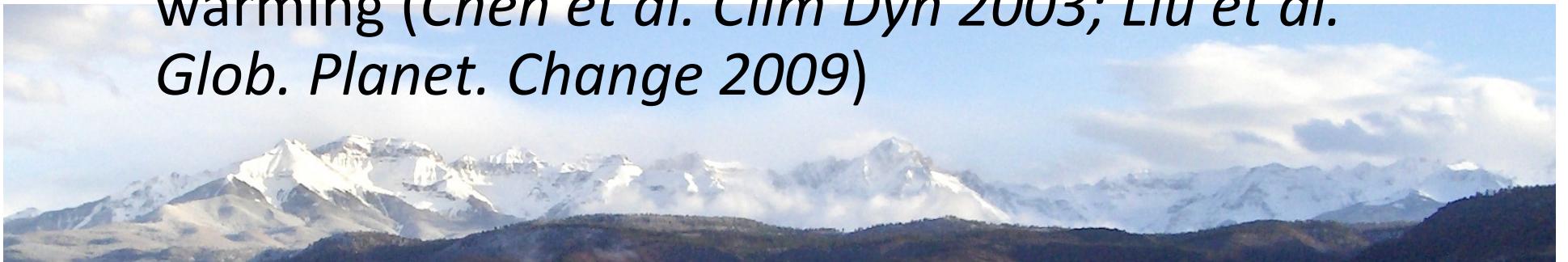
- Increase in specific humidity in Tibetan Plateau (1961-2000) => larger DLR => higher temperature esp. in winter and spring (*Rangwala et al GRL 2009*)

Estimated change in DLR based on observed change in specific humidity per season and elevation range



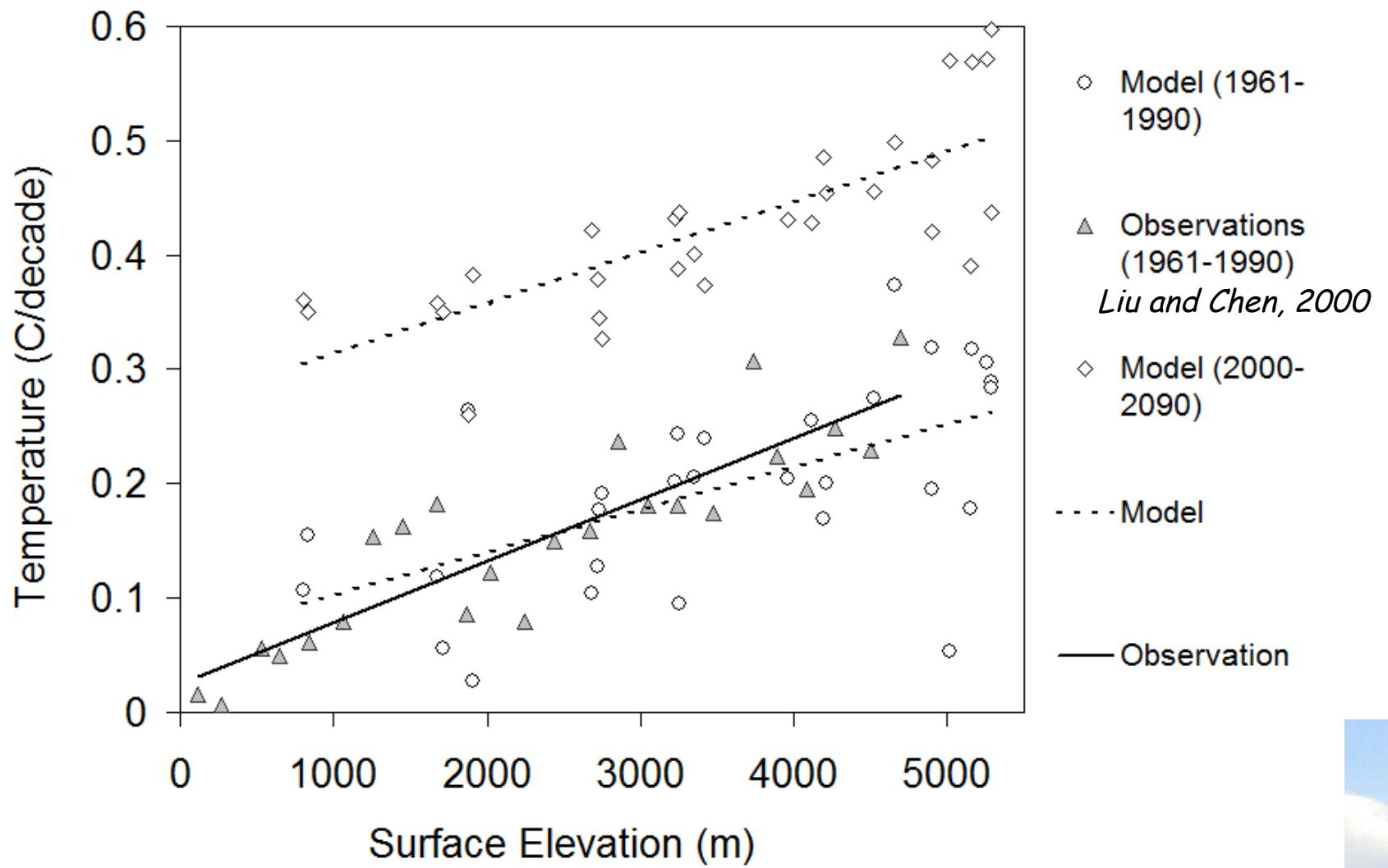
# Model studies

- Soot: positive feedback in Rockies, esp. noticeable in late winter-spring, when melt season active. (*Qian et al. JGR 2009*)
- Humidity and change in snow cover both involved in simulated warming over Tibetan Plateau (*Rangwala et al. Clim Dyn 2010*)
- Cloud feedback to the east and snow cover to the west of Tibetan Plateau can explain simulated warming (*Chen et al. Clim Dyn 2003; Liu et al. Glob. Planet. Change 2009*)



Tibetan  
Plateau

# Observed vs Modeled: Elevation Dependent Warming

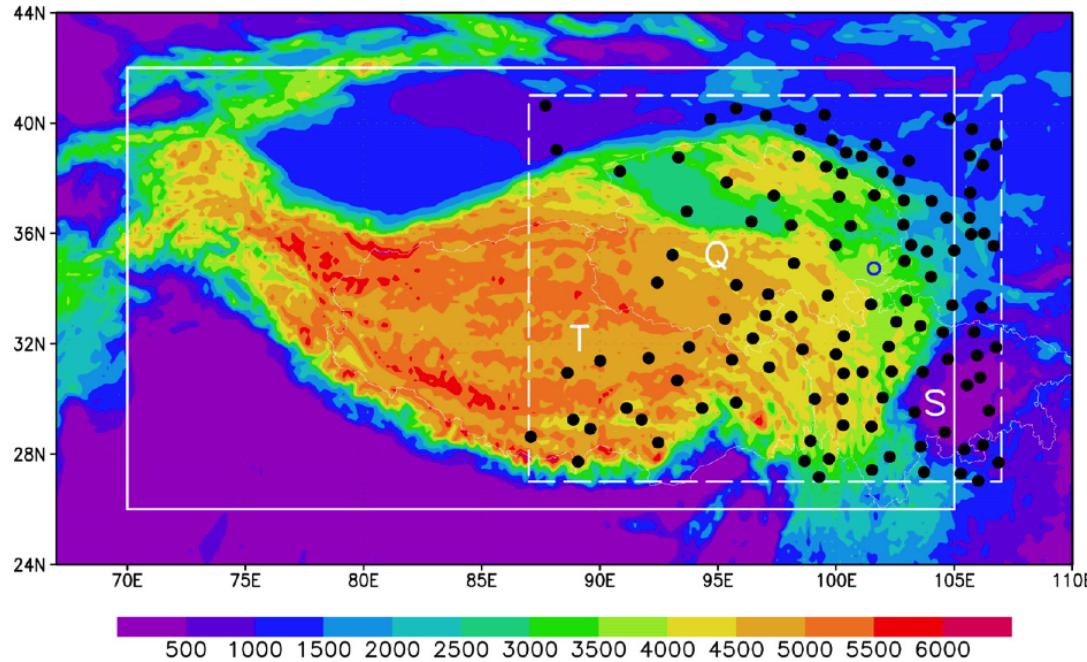


# Sensitivities + issues

- Rockies: sensitivity to dust and soot => snow melt=> albedo => higher temperatures (observations and models)
- Tibet: sensitive to changes in clouds (esp. Eastern), in water vapor, and in snow cover (ep. West)
- => need more observations to decide importance of each factor



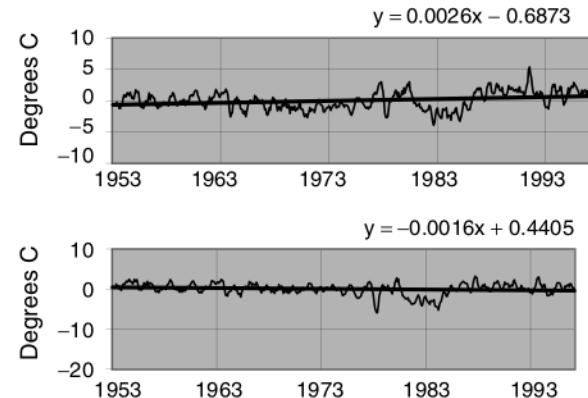
# Issues with observations



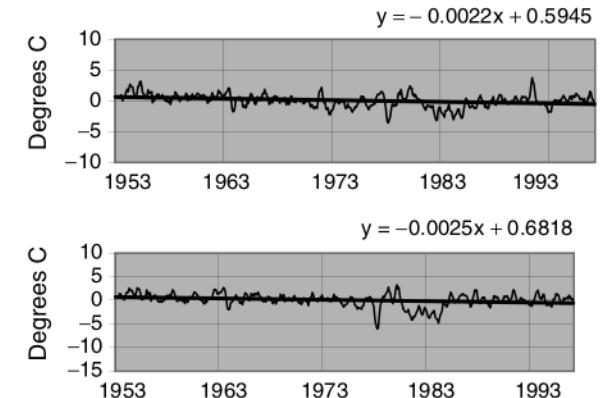
Limited network: Altitude distribution of Tibetan Plateau (Liu et al 2009) with some of the meteorological stations (note the lack of stations to the west).

Different trends in different locations: *cooling* observed on the eastern side of the Rockies *Pepin and Losleben (IJC 2002)*  
Impact of Topography?  
Large scale?

3000m: max and min T trends



3700m: max and min T trends



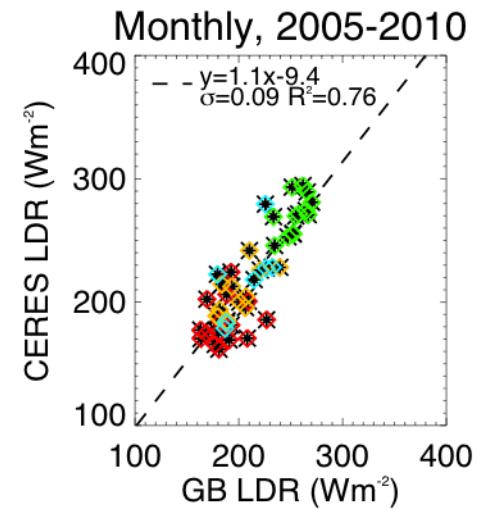
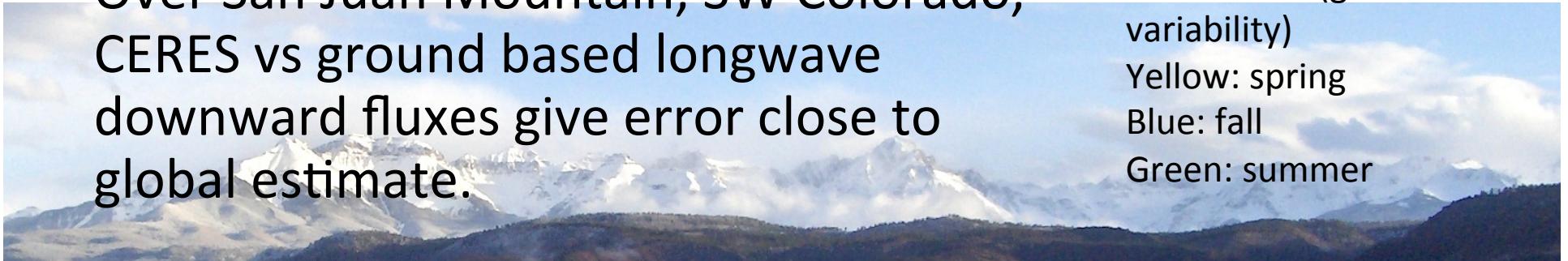
# Satellite view: strengths and weaknesses

- Satellite have global view, and can observe remote areas on a regular time step
- Resolution may cause issues where altitudes highly variable
- Bright surfaces not great for remote sensing
- Short period available (30 years max), not great for trends
- Multiple variables observed simultaneously, so inter-relationships can be observed=> ideal to study feedback loops
- => How do existing products perform in tricky areas such at Tibet or Rockies?



# Radiation

- Yang et al tested retrievals over the Tibetan Plateau region of surface shortwave (JGR 2008, GRL 2009) and longwave fluxes (GRL 2009) from various missions and found large errors over highly varying terrain but less so over the Tibetan Plateau itself (close to global average). Issue is surface and atmosphere inputs.
- Over San Juan Mountain, SW Colorado, CERES vs ground based longwave downward fluxes give error close to global estimate.



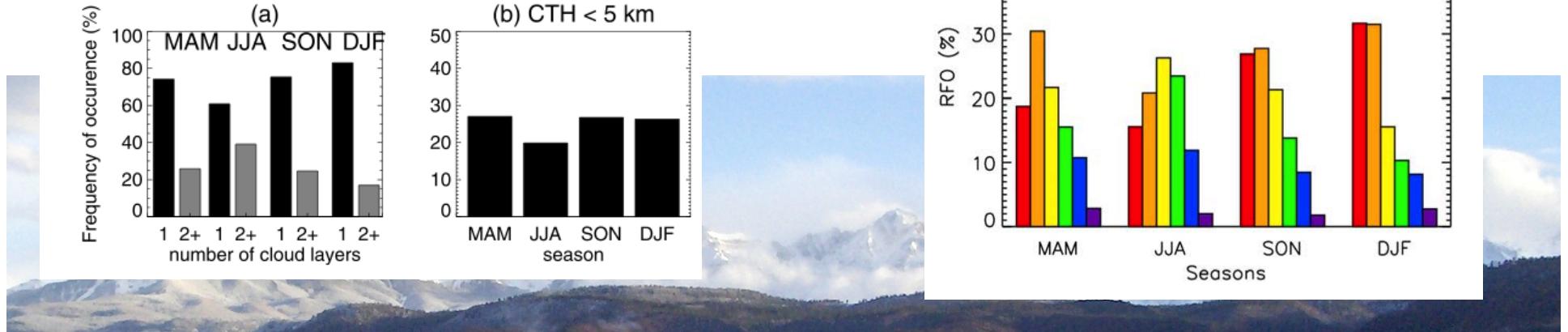
Red: winter (greater variability)  
Yellow: spring  
Blue: fall  
Green: summer

# Clouds

- ISCCP vs CloudSat-CALIPSO cloud frequency of occurrence over Tibetan Plateau:
  - ISCCP misdetection of clouds within 5 km of surface or optically thin (problematic in winter)
  - ISCCP CTP overestimated when multiple layers: relatively rare in winter over Tibetan Plateau

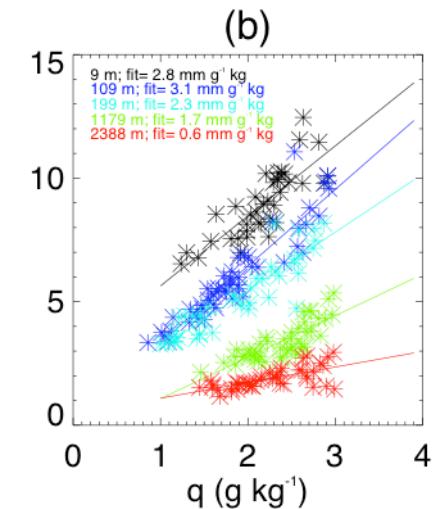
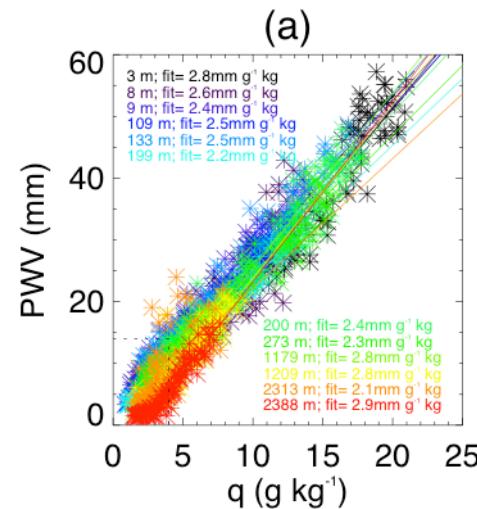
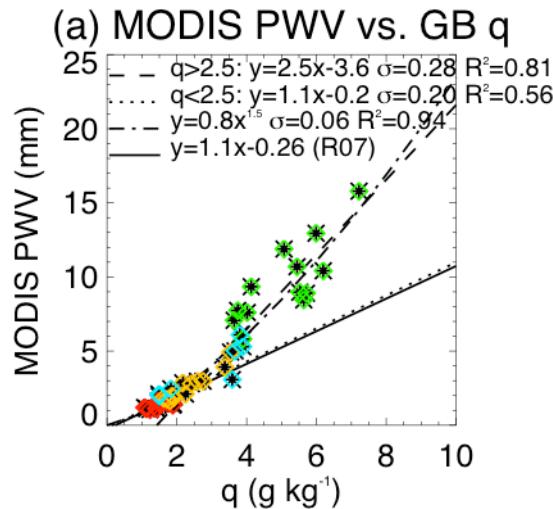
Errors in ISCCP cloud products consistent with lower altitude estimates

*Naud and Chen JGR 2010*



# Water vapor

- MODIS PWV vs surface specific humidity: San Juan observations from Center for Snow and Avalanche Studies => MODIS PWV vs q similar relation as GPS vs q for Alps



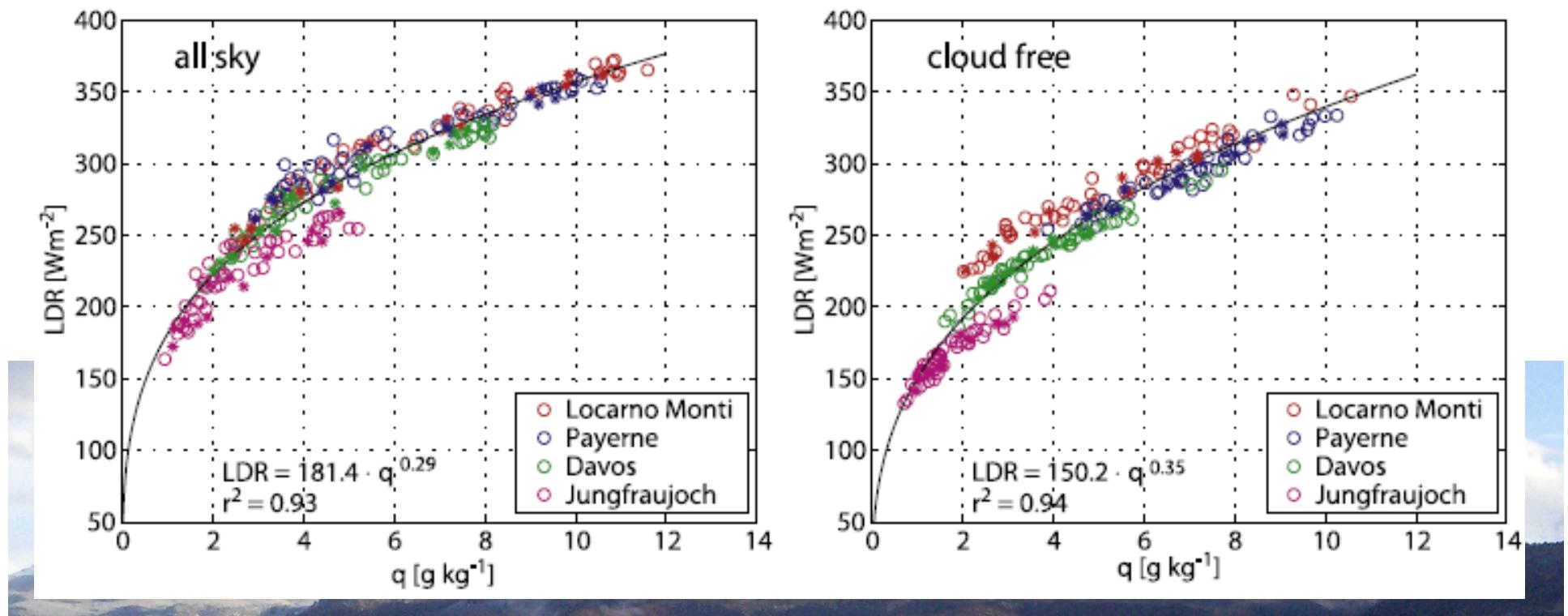
MODIS PWV vs GB q: agree for low values of q with GPS vs q in the Alps at similar elevation, but not for large q

MODIS vs Weather stations across the US: for  $q > 4 \text{ g kg}^{-1}$  linear relation between MODIS PWV and surface q (slope  $\sim 2.5$  = Ruckstuhl et al 2007 for the Alps and GPS PWV)

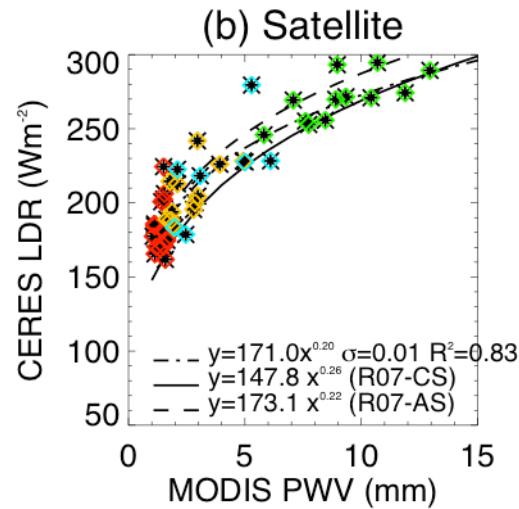
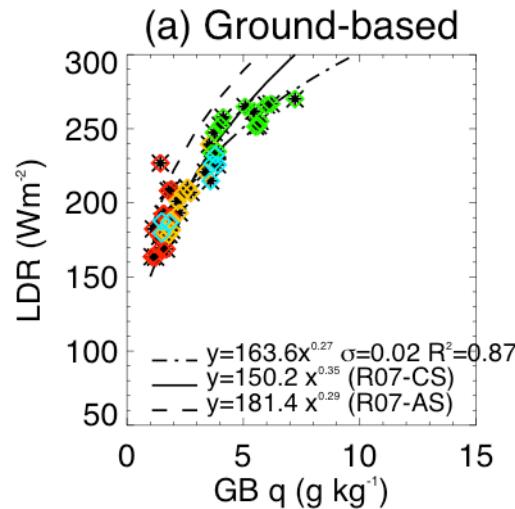
# LDR vs humidity: Alps

- Ground based relationship for 4 stations from 388 to 3584 m; *Ruckstuhl et al. JGR 2007*

*Monthly means in DLR and q from 2001-2004*

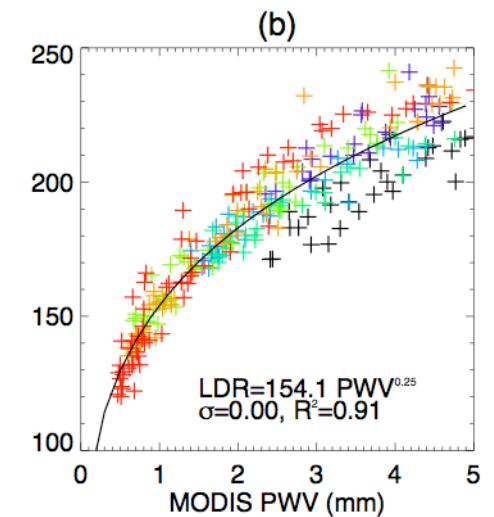
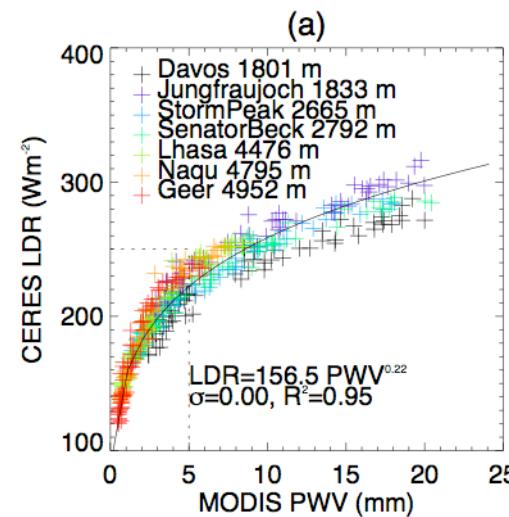
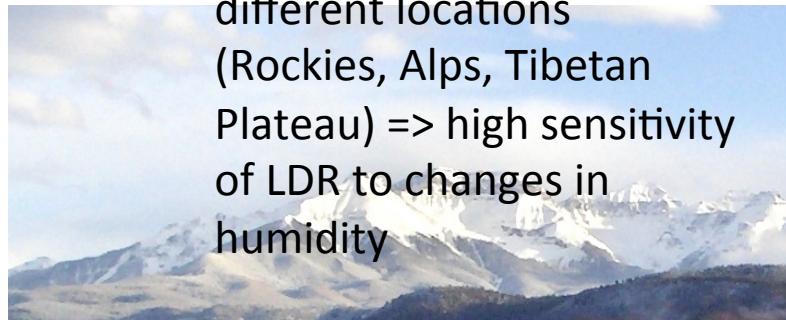


# Satellite based relationship LDR vs humidity



CERES & MODIS vs Ground-based derived relationship at San Juan: agreement with similar study over the Alps

Relationship CERES LDR/  
MODIS PWV preserved for  
different locations  
(Rockies, Alps, Tibetan  
Plateau) => high sensitivity  
of LDR to changes in  
humidity



# Conclusions

- Warming at high elevations at greater rate than other altitudes
- Which factors accelerate warming at high elevations?
- Satellite retrievals could be used to study feedback loops at high elevations, even if errors larger

